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IMPROVING CHICKPEA MATURITY THROUGH MANAGEMENT OF THE INDETERMINATE GROWTH HABIT

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Improving Chickpea Maturity through Management of its Indeterminate Growth Habit

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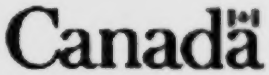

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TABLE OF CONTENTS

EXECUTIVE SUMMARY 4

RATIONALE 4
OBJECTIVES 4
EXPERIMENTS 4
MATURITY 4
SEED YIELD 5
SEED SIZE 5
NODULATION 6
WATER RELATIONS 6
ACKNOWLEDGEMENTS 2

METHODOLOGY 7

SITES AND TREATMENTS 7
EXPERIMENTAL DESIGN 7
PLOT MANAGEMENT 7
DATA COLLECTION 8
a) Plant stand and biomass *8*
b) Maturity rating *8*
c) Nodulation *9*
d) Harvest index *9*
e) Seed yield and seed size distribution *10*
STATISTICAL ANALYSIS 10

RESULTS AND DISCUSSION 11

ENVIRONMENTAL CONDITIONS 11
CHICKPEA MATURITY 13
a) Year effect on chickpea maturity *13*
b) Stubble type effect on chickpea maturity *13*
c) Maturity differences among varieties *14*
d) Fertility and inoculation effect on chickpea maturity *14*
SEED YIELD AND HARVEST INDEX 18
a) Year and stubble effect on seed yield *18*
b) Yield differences among sites and varieties *19*
c) Fertility treatments effect on seed yield *22*
SEED SIZE DISTRIBUTION IN KABULI CHICKPEA 23
a) Year, stubble, and variety effect on seed size distribution *23*
b) Fertility and inoculation effect on seed size distribution *25*
ROOT NODULATION 26
a) Year and stubble type effect on nodulation *26*
b) Cultivar differences in nodulation *28*
SOIL N CHANGES DURING THE GROWING SEASON 29
WATER RELATIONS 30

CONCLUSIONS 31

TECHNOLOGY TRANSFER 32

EXECUTIVE SUMMARY

RATIONALE

Chickpea is a long-season annual legume with a strong indeterminate growth habit; when moisture conditions are favourable the plants continue their vegetative growth without setting pods or by filling only a few pods. In the short-seasoned western Canada, late maturity is one of the biggest challenges for the commercial production of chickpea. During the past 10 years, there were at least three years (1999, 2002, 2004) when chickpea producers in western Canada faced difficulties to harvest their chickpea crops by the onset of late-fall killing frost. Late-matured chickpea produced low seed yield with poor seed quality. High proportion of green seed in harvested seedlots of late-matured chickpea results in a large price discount by consumers.

OBJECTIVES

This project was to (i) determine the effect of preceding stubble type (barley, wheat, and summerfallow) and fertility/inoculation management on chickpea maturity, and (ii) to develop cropping strategies and practices that manage the indeterminate growth habit and promote the maturity of chickpea crops.

EXPERIMENTS

Field experiments were conducted at Swift Current and Shaunavon, Saskatchewan, between 2004 and 2006. Four market classes of chickpea (1) large-seeded kabuli chickpea 'CDC Xena' (465 mg seed^{-1}), (2) medium-sized kabuli chickpea 'CDC Frontier' (365 mg seed^{-1}), 3) small-sized kabuli chickpea 'Amit'(260 mg seed^{-1}), and 4) desi chickpea 'CDC Anna' (210 mg seed^{-1}) were grown on wheat and barley stubble and also on conventional summerfallow. Eight fertility/inoculation treatments were applied to each of the four varieties by three stubble type combinations in a randomized split-plot design with four replicates. Maturity progress was monitored and recorded on each plot starting from when plants began turning colour. Seed yield, protein, and root nodulation were also determined.

MATURITY

Large differences in plant maturity were observed among fertility treatments in the wet/cool year of 2004 and the normal year of 2005. Plots that received no-N and no-inoculant, and plots with no-N but with granular inoculant matured latest. The advancement in days of maturity was greatest when plants were fertilized at the rate of 28 to 56 kg N ha^{-1} without using inoculant. In the wet/cool years, use of fertilizer at 28 to 56 kg N ha^{-1} without using inoculant advanced maturity by 15 days for CDC Anna, 13 days for CDC Frontier, 12 days for Amit, and 8 days for CDC Xena. In normal years, the maturity advancement due to fertilization was less than that observed in wet/cool years, but maturity responses to fertility treatments were significant. Averaged across four site-

years (i.e., two sites in two years), the use of fertility at 56 kg N ha^{-1} advanced chickpea maturity by 13 days. Among the four chickpea cultivar types, CDC Anna and CDC Frontier received the greatest benefit from the fertilization. However, in the dry year of 2006, only marginal differences were found among the fertility treatments. Drought conditions during podding stages accelerated crop maturity regardless of soil fertility.

SEED YIELD

On average, seed yield was highest in 2004 (2240 kg ha^{-1}), intermediate in 2005 (2070 kg ha^{-1}), and lowest in 2006 (1200 kg ha^{-1}). In 2004, the average seed yield of chickpea was 10% higher when grown on barley stubble, and 21% higher when grown on wheat stubble, compared to summerfallow. This was because chickpea grown on summerfallow at Shunavon did not reach full maturity, whereas chickpea grown on summerfallow at Swift Current in 2004 contained 45% green seeds due to incomplete maturity by the onset of a killing frost. In the normal year of 2005, seed yields were similar among the three stubble systems. In the dry year of 2006, chickpea yields averaged 67% higher when grown on summerfallow compared to barley stubble, and nearly double the yield of chickpea grown on wheat stubble. CDC Frontier showed consistently higher seed yield than CDC Xena. Also, CDC Frontier displayed greater yield stability than CDC Xena across various environmental conditions.

Averaged over the six site-years, plots that were not supplied with either fertilizer N or inoculant (i.e., 0N check treatment) produced seed yield of 1500 kg ha^{-1} or less, whereas the seed yield of chickpea that was inoculated with *Rhizobium* was 27% higher than the check. The seed yield of chickpea supplied with N fertilizer at the rates of 28 and 56 kg N ha^{-1} but no *Rhizobium* was 18% greater than the check. Plots that received *Rhizobium* inoculant plus N fertilizer at the rates of 28 or 84 kg N ha^{-1} produced yields similar to or slightly higher than those that were inoculated with *Rhizobium* but without fertilizer additions.

Seed yield response to soil fertility/inoculation was influenced by weather conditions. In the wet/cool year of 2004, plots that received N fertilizer at the rates of 28 and 56 kg ha^{-1} produced greater proportion of high quality, marketable seeds due to earlier maturity, whereas the plots that were inoculated with *Rhizobium* produced a larger portion of green seed due to delayed maturity. Percent of green seed was less than 2% in 2005 and near zero in 2006, regardless of fertility treatment.

SEED SIZE

Fertility/inoculation treatments did not have any impact on seed size distribution in CDC Xena, but they had somewhat impact on seed size distribution of CDC Frontier. CDC Frontier chickpea inoculated with *Rhizobium* granular inoculant produced 28% of ≥9 mm diameter seed, compared to 22% for CDC Frontier that received N-fertilizer or no-N no-inoculant. CDC Xena grown on barley stubble produced 59% of seeds ≥9 mm, 6 percentage points higher than for CDC Xena grown on wheat stubble. The advantage of growing kabuli chickpea on conventional summerfallow was realized only in the dry year of 2006 when the fallow-grown CDC Xena produced 60% of ≥9 mm seeds, higher than when grown on barley (35%) or wheat (31%) stubble.

NODULATION

On average, kabuli chickpea had consistently greater nodulation in terms of number of nodules and nodule dry weight than desi chickpea. The difference in nodulation between the two chickpea types was about 50% at 1st flower, and 46% at the end of flowering. Greater seed yield in CDC Frontier than CDC Anna was partly due to greater nodulation activity in CDC Frontier during flowering. Both the number of nodules and nodule dry weight were consistently lower on chickpea grown on summerfallow compared to stubble, largely due to higher residual soil N on the fallow fields. Nodulation of the 2006 chickpea crop was only a portion of the nodulation observed on the 2004 and 2005 chickpea crops, due to drought conditions in 2006.

WATER RELATIONS

Growing season (May-August) precipitation encountered in this study ranged from 105 to 283 mm across the six site-years. In general, seed yields of all varieties increased as precipitation increased while the protein content of the grain decreased substantially. CDC Xena had consistently the lowest seed yield across varying environments, while CDC Anna had consistently low protein content. Protein content in chickpea ranged from 12% to 25% across the varying environments; the range of protein content was greater than expected.

METHODOLOGY

SITES AND TREATMENTS

Field experiments were conducted at two sites; Swift Current and Shaunavon, Saskatchewan, from 2004 to 2006. At both sites, the following four market classes of chickpea were tested: (1) large-seeded kabuli chickpea 'CDC Xena' (465 mg seed^{-1}), (2) medium-sized kabuli chickpea CDC Frontier' (365 mg seed^{-1}), 3) small-sized kabuli chickpea 'Amit'(260 mg seed^{-1}), and 4) desi chickpea 'CDC Anna' (210 mg seed^{-1}). Each variety was grown on wheat and barley stubble and on conventional summerfallow. The following fertility/inoculation treatments were applied to each variety by stubble combination:

1) No-N and no-inoculant (control);
2) No-N, granular (GR) inoculant;
3) N=28 kg ha^{-1}, no-inoc.
4) N=56 kg ha^{-1}, no-inoc.
5) N=84 kg ha^{-1}, no-inoc.
6) N=112 kg ha^{-1}, no-inoc.
7) N=28 kg ha^{-1}, with GR inoc.
8) N=84 kg ha^{-1}, with GR inoc.
9) flax as non-N-fixer reference crop.

EXPERIMENTAL DESIGN

In 2004, the 33 treatments (4 varieties x 8 fertility + flax) were arranged in a randomized complete block design with 4 replicates with the three stubble conditions located on adjacent fields. In 2005 and 2006, a split-plot design was used with four replicates, where stubble type was designated as main plot and variety x fertility/inoculation as sub-plots (2 x 10 m). In each of the six site-years, there were 396 experimental units.

PLOT MANAGEMENT

Plots were managed using recommended agronomic practices such as seeding practices and pest control. In brief, seed was treated with carbathiin, thiabendazole, and metalaxyl at label recommended rates to manage soil- and seed-borne diseases. Seed was planted at 50 mm depth on the date when noon soil temperature at the 10-cm soil depth was between 10 and 15°C. Plots were seeded with a research plot drill equipped with C shanks, side band openers, fertilizer boxes, inoculant box, and a seed splitter. Seeding rates were determined based on pre-seeding germination rate, seed size, and estimated field emergence rate of 75%, targeting a plant population density of 40 plants m^{-2}. All plots received a blanket application of 38 kg ha^{-1} of 0-45-0 fertilizer with the seed to supply P. Plots that needed *Rhizobium* inoculant as part of the experimental design received 5.5 kg ha^{-1} of 'Nitragin GC®', in a granular form (LiphaTech Inc., Milwaukee, WI). Weed control was achieved using a previous fall broadcast of ethafluralin at 22 kg ha^{-1}, a pre-seeding burn-off treatment with glyphosate, and in-crop application of

sethoxydim during the mid-seedling stage. Ascochyta blight was noted on the chickpea crops during the mid-seedling stage each year. Depending on years, three to four applications of chlorothalonin (Syngenta Crop Protection Canada, Inc.) at 0.5 - 0.65 L product ha^{-1} and pyraclostrobin (Bayer Crop Science, USA) at 0.6 - 1.0 L product ha^{-1} were used to minimize disease damage. The foliar fungicide applications were applied with 220 L ha^{-1} of water at 275 kPa pressure using standard flat fan nozzles.

DATA COLLECTION

a) ***Plant stand and biomass***

Plant establishment was assessed 10 to 12 days after initial seedling emergence by counting the number of plants in a 1-m length in each of two rows at two places in each plot. Aboveground biomass was sampled from a 0.50-m^2 area of the center four rows of a plot at each of the following developmental stages: seedling, early flower, late flower, late-pod, and maturity. At each sampling date, biomass samples were oven dried at 60°C for 7 to 10 d and weighed. In order to compare data among different site-years, growing degree days were calculated using a base temperature of 5°C. Crop growth rate was calculated by regressing biomass (dependent variable) against time (independent variable) in the linear portion of growth.

b) ***Maturity rating***

The progress of plant maturity was monitored and recorded every 6 to10 days starting when plants first began to turn colour. A maturity index was developed (Table 1) and used for the assessment of the maturity progress in a quantitatively manner.

Table 1. Maturity Index (MI) used for the assessment of maturity progression in chickpea

MI	Description
0	Zero % color change in plant
1	Slight color change (10%) on some of the plants
2	20% color change on some of the plants
3	10-30% color change on majority of the plants
4	About 40% color change on majority of plants with pods showing slight color change
5	About 50% color change on majority of plants with pods showing definite color change (lime green to tan)
6	About 60% color change on majority of plants with 60% of pods turning tan color
7	About 70% color change on majority of plants with 70% of pods tan colored
8	About 80% color change on majority of plants with 80% of pods tan color including some ripe pods (physiological maturity)
9	Over 90% of pods tan coloured and/or ripen, and almost all plants are dried down with some green tops remaining

10	All pods are ripe and all plants are dried down with little to none green tops on plants remaining

Maturity Index (MI) ratings were regressed against time (Fig. 1) and the regression was used to determine a calendar and Julian date when the plants had reached physiological maturity (i.e., MI=8). Maturity index=8 was used to compare treatment effects.

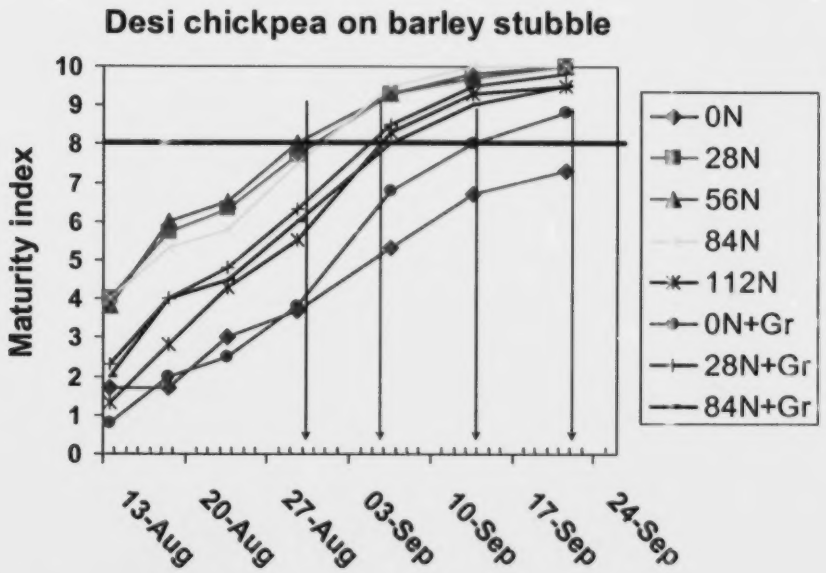

Fig. 1. Using desi chickpea grown on barley stubble at Shaunavon in 2004 as an example, crop maturity was quantified using a "Maturity Index" rating which started when plants first began to turn colour. A Maturity Index of 8 means 80% of the pods had turned colour and the plants had reached physiological maturity.

c) ***Nodulation***

At early- and late-flowering stages, root nodules were evaluated on 10 plants that were randomly collected from each plot. The plant root-soil matrix was excavated to a soil depth of approximately 60 cm, and were placed in water and soaked to aid in soil removal while retaining the nodules on the roots. After initial soil removal, the plants were placed in bags with some water and transferred to a cold room (4 °C) until the time of evaluation within 48 h. The number of nodules, nodule dry weight, nodule distribution on root systems, and nodule functionality (judged based on colour) were determined on each plant and a mean value per plot was used for statistical analysis.

d) ***Harvest index***

At full maturity, a 0.5-m^2 area was hand harvested from each plot; seeds and straw were dried in an oven at 40°C and weighed separately. Harvest index was calculated as the ratio of seed dry weight to total biomass.

e) ***Seed yield and seed size distribution***

The centre five rows of each plot ranging from 7 to 13 m2were harvested with a plot combine when the crop had dried sufficiently for satisfactory threshing. The seed samples were air-dried, cleaned, weighed, and seed yield presented on a dry weight basis. Proportions of different seed sizes of kabuli chickpea were determined by passing the harvested seed sample through a series of sieves, and the percentage (by weight) was calculated for each seed size category. In addition, the percentages of green seeds in the harvested seed samples were counted.

STATISTICAL ANALYSIS

Data were analyzed using analysis of variance in the general linear model procedure (PROC GLM) of SAS (SAS Institute, Inc. 2001). Site by year interactions were not significant for most of the variables measured, but year by treatment interactions were highly significant. Therefore, the data from the two sites were averaged in most case, but the data in each of the three years were presented separately. In the analysis, chickpea cultivar and stubble type were considered as fixed effects, and site and replicate as random effects. Means were separated by Fisher's protected Least Significant Difference (LSD) test at $P \leq 0.05$.

RESULTS AND DISCUSSION

ENVIRONMENTAL CONDITIONS

Seedbed soil moisture measured at spring seeding was adequate in all six site-years with the residual soil water in the 0-30 cm depth ranging from 22 to 39 mm (Table 2). Seedbed moisture at Swift Current in 2004 was slightly lower than in the rest of the site-years, but greater than average rainfall in May (particularly after seeding) (Table 3) helped seedling emergence. Adequate seedbed soil moisture allowed excellent plant establishment at all site-years with average plant stands ranging between 32 and 45 plants m^{-2}, which was near optimum plant density for chickpea production. On average, growing season (May-August) precipitation in 2004 was 30% greater than the long-term average (210 mm), while growing season precipitation in 2006 was 25% below the long-term average (Table 3). The 2005 was an average year with both precipitation and air temperatures being near normal.

Table 2. Seedbed soil moisture (mm) measured at 0-30 cm depth at spring seeding

Seedbed	Swift Current				Shaunavon			
	2004	2005	2006	3-yr mean	2004	2005	2006	3-yr mean
Fallow	23.6	37.5	32.4	31.2	35.3	29.5	34.8	33.2
Barley	21.7	39.4	30.0	30.4	25.0	30.7	39.0	31.6
Wheat	23.8	38.3	30.2	30.7	29.4	32.3	37.0	32.9
Mean	23.0	38.4	30.9	30.8	29.9	30.8	36.9	32.5

Table 3. Weather data at the experimental sites

Month	Swift Current				Shaunavon			
	2004	2005	2006	45-yrs [z]	2004	2005	2006	30-yrs [y]
Precipitation (mm)								
May	83.7	22.4	43.5	44.8	67.6	57	17.0	57.2
June	66.2	123.2	99.9	71.7	48.5	82.1	52.1	68.5
July	61.1	21.4	26.3	48.1	70.6	52	11.4	52.4
August	72.3	52.1	24.1	41.2	85.6	41.7	25.0	36.4
Total	283.3	219.1	193.8	205.7	272.3	232.8	105.6	214.5
Mean air temperature (°C)								
May	8.3	9.9	12.5	10.8	7.6	9.4	12.1	11.2
June	13.0	14.7	16.2	15.5	13.6	14.7	15.3	15.5
July	17.8	18.6	21.2	18.3	17.9	18.7	20.6	18.2
August	15.3	16.5	19.2	18.0	15.2	16.3	18.1	17.6
Mean	13.6	14.9	17.3	15.6	13.6	14.8	16.5	15.6

[z] 1960-2004 at Agriculture and Agri-Food Canada Research Centre
[y] 1971-2000, obtained from Environment Canada weather station at Shaunavon

CHICKPEA MATURITY

a) ***Year effect on chickpea maturity***

There was a large variation in chickpea maturity among the three study years. Averaged over two sites each year, in 2004, chickpea crops took an average of 153 days to reach maturity from seeding, compared to 105 days in 2005 and <90 days in 2006 (Fig. 2). The large difference in maturity among years was due to growing season precipitation and temperature (Table 3). Chickpea in 2004 had a slower start with slow vegetative growth, a prolonged growing season, and delayed harvest. In comparison, chickpea in 2006 had a rapid seedling growth, shortened vegetative growth period, and rapid maturity.

b) ***Stubble type effect on chickpea maturity***

Chickpea grown on conventional summerfallow did not reach full maturity by the onset of late-fall frost at Shaunavon in 2004, and was delayed by an average of 6 days in 2005 and 2006 compared to chickpea grown on barley stubble. Chickpea grown on wheat stubble had a similar maturity as chickpea grown on barley stubble in 2005 and 2006 (Fig. 2); however, in 2004 chickpea grown on barley stubble matured 5 days earlier than when grown on wheat stubble. The conventional summerfallow field at Shaunavon in 2004 had much greater residual soil N at spring seeding than soil N measured in barley and wheat stubble fields; this may have contributed to the delayed maturity for chickpea grown on summarfallow. There was no differences in spring soil nutrients or soil moisture at seeding between barley and wheat stubble, thus, there was no difference in maturity of chickpea grown on barley and wheat stubble in either 2005 or 2006. The reason is unknown as to the maturity differences observed in 2004 between barley and wheat stubble.

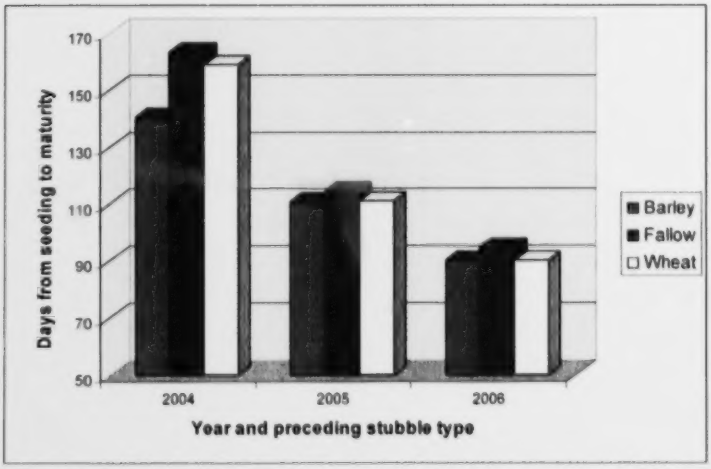

Fig. 2. Effect of preceding crop type on maturity of chickpea grown in 2004, 2005, and 2006 (Note that the different stubble types in 2004 were in adjacent fields, whereas the stubble types in 2005 and 2006 were arranged in split-plot design). Data were means of the two sites in each year because there was no site by year interaction.

c) ***Maturity differences among varieties***

There were large differences in maturity among varieties (Fig. 3). In general, CDC Frontier matured latest and the variety Amit the earliest under the same growing conditions. In the wet/cool year of 2004, the differences in days to maturity between the earliest (Amit) and the latest (CDC Frontier) was 8 days, whereas in the dry/warm year of 2006, their difference was less than 5 days. These values represent the average across all stubble x fertility treatments. There existed year by variety interaction for maturity (Fig. 3) where CDC Xena matured earliest in 2004 and 2005 but the latest in 2006. The reason for the interaction was unknown.

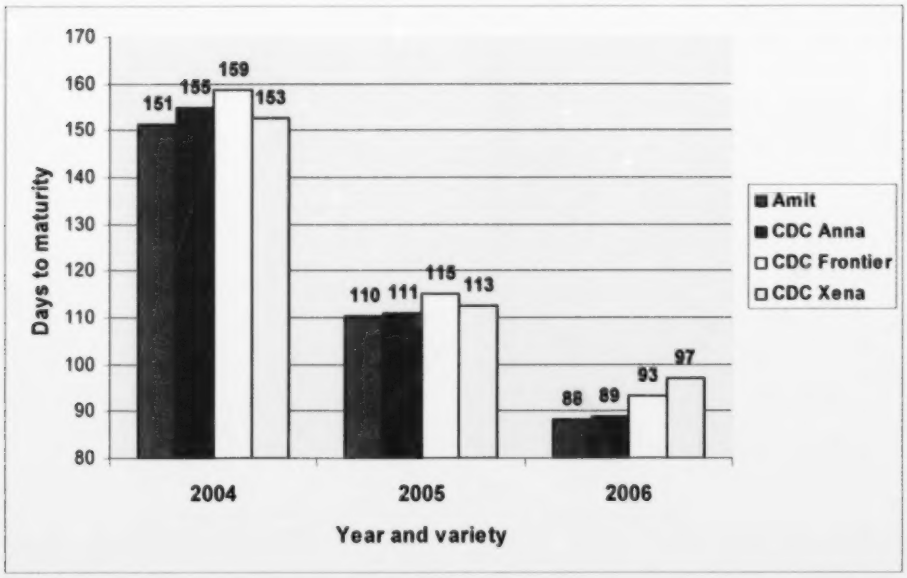

Fig. 3. Differences in maturity among four chickpea varieties grown in 2004, 2005, and 2006, at Swift Current and Shaunavon.

d) ***Fertility and inoculation effect on chickpea maturity***

Substantial differences in plant maturity were observed among fertility treatments in the wet/cool year of 2004 and also differences were observed in the normal year of 2005 (Fig. 4). In both years, plots that received no-N and no-inoculant, and plots with no-N but with granular inoculant, matured latest at both locations (Fig. 5). The number of days of maturity advance was greatest when plants were fertilized at the rate of 28 to 56 kg N ha^{-1} without using inoculant.

Averaged over the two sites, in 2004, use of fertilizer at 28 to 56 kg N ha^{-1} without using inoculant advanced maturity by 30 days for Amit, 26 days for CDC Anna, 29 days for CDC Frontier, and 21 days for CDC Xena (Table 4). In 2005, the fertility treatments advanced maturity in a similar pattern as

those observed in 2004, but the degree of the maturity advancement among treatments was less than that of 2004. In 2005, the averages over the two sites showed that use of fertilizer at 28 to 56 kg N ha^{-1} without using inoculant advanced maturity by 5 days for Amit, 6 days for CDC Anna, 5 days for CDC Frontier, and 2 days for CDC Xena. Averaged over the two years, two sites, and four cultivars, the application of 56 kg N ha^{-1} advanced chickpea maturity by 13 days. Among the five chickpea cultivars, CDC Anna and CDC Frontier received the greatest benefit from fertilization.

However, in the dry/warm year of 2006, there were no differences between the check and the plots receiving 28 to 56 kg N ha^{-1}, and only marginal differences in maturity were observed among the rest of the fertility treatments (Table 4). Drought conditions in the late growth stage in 2006 accelerated crop maturity.

2004 Shaunavon

2005 Shaunavon

Fig. 4. Substantial differences in chickpea maturity were observed in the wet/cool year of 2004 (top) and also in the normal year of 2005 (right). However, the differences in chickpea maturity among treatments were marginal in the dry/warm year of 2006 (photo not shown).

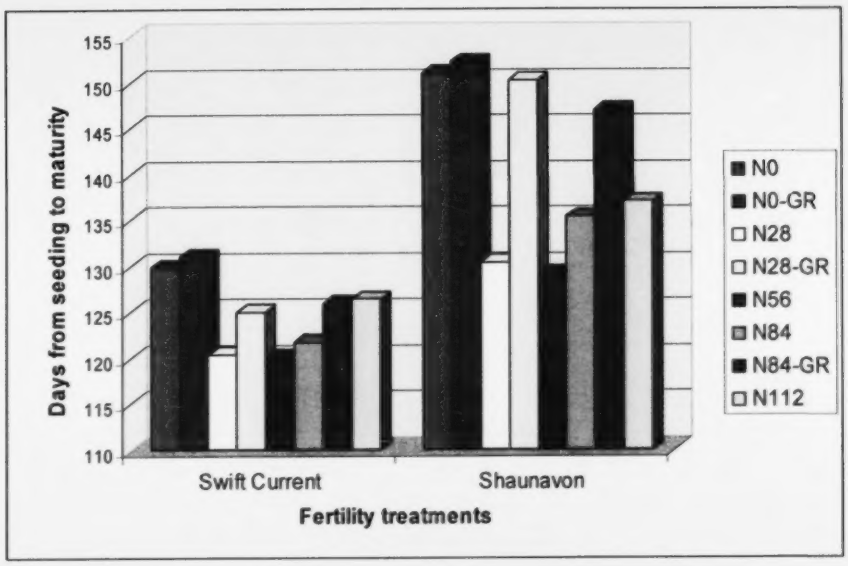

Fig. 5. Days to maturity of chickpea grown at Swift Current and Shaunavon, using various fertility and inoculation management schemes (Note: N0-GR means the crop received no nitrogen fertilizer but granular inoculant). Data were averaged over the wet/cool year of 2004 and the normal year of 2005 in this graph to emphasize the importance of this effect when chickpea maturity faces the greatest challenge. Data from 2006 were excluded in this graph to address that in dry years the maturity of chickpea may not be an issue in commercial production.

In general, the differences in chickpea maturity due to fertility treatments were greater at Shaunavon than at Swift Current (Fig. 5). The reason for the maturity differences between the two sites is unknown, but we speculate that it could be due to chickpea growing history. Chickpea had been grown at the Swift Current site for the past 10 years and the soil may have had more residual *Rhizobium* that may function for N-fixation even without application of new inoculant; this may have eliminated the potential fertility effect on maturity. Further research is needed to elucidate this effect.

Table 4. The number of days in maturity advancement from the check for four chickpea cultivars tested in southwest Saskatchewan, during the 2004-2006 growing seasons which had distinct weather conditions.

Fertilizer at kg N ha^{-1} with/without inoculant (GR)	Cultivar					Growing season weather conditions			
	Amit	CDC Anna	CDC Frontier	CDC Xena	Average	Precip. (mm)	% greater than long-term average	Temp. (°C)	% greater than long-term average
					2004				
0 (check) †	***166.7***	***162.8***	***171.5***	***162.5***	***165.9***	278	32%	13.6	-13%
28	29.5	26.2	28.3	20.5	26.1				
56	30.0	25.7	29.8	20.8	26.6				
84	25.7	19.5	17.5	19.0	20.4				
112	22.8	11.5	13.7	14.3	15.6				
N=0, w/GR	0.0	-13.7	2.3	-1.2	-3.1				
N=28, w/GR	2.5	-3.0	5.8	2.7	2.0				
N=84, w/GR	11.7	-1.8	4.7	3.5	4.5				
Significance	**	**	**	**	**				
					2005				
0 (check)	***113.8***	***115.2***	***117.8***	***113.3***	***115.0***	226	7%	14.8	-5%
28	4.8	5.0	3.5	2.5	4.0				
56	5.8	6.5	5.7	2.0	5.0				
84	5.5	4.2	3.3	0.3	3.3				
112	2.3	4.7	2.2	-2.0	1.8				
N=0, w/GR	0.5	2.5	0.3	-0.7	0.7				
N=28, w/GR	3.8	4.8	3.8	2.0	3.6				
N=84, w/GR	4.5	5.2	3.0	1.3	3.5				
Significance	**	**	**	**	**				
					2006				
0 (check)	***87.2***	***87.0***	***91.3***	***94.2***	***89.9***	150	-29%	16.9	8%
28	1.3	0.0	0.0	-1.3	0.0				
56	-1.2	-1.8	-2.7	-3.2	-2.2				
84	-1.8	-3.2	-4.5	-4.5	-3.5				
112	-3.7	-5.3	-3.5	-5.7	-4.5				
N=0, w/GR	0.2	-1.0	-0.8	-0.8	-0.6				
N=28, w/GR	0.2	-1.0	-0.8	-2.0	-0.9				
N=84, w/GR	-2.3	-2.8	-4.3	-4.7	-3.5				
Significance	NS	*	NS	**	*				

† The numbers for the check treatments are the actual number of days from seeding to maturity, and the numbers for the rest of the treatments are the number of days advanced in maturity from the check.
*, **, and NS indicate significant at $P<0.05$, $P<0.01$, and Not significant, respectively.

SEED YIELD AND HARVEST INDEX

a) ***Year and stubble effect on seed yield***

Averaged over the Swift Current and Shaunavon sites, seed yields were highest in 2004 (2240 kg ha^{-1}), intermediate in 2005 (2070 kg ha^{-1}) and lowest in 2006 (1200 kg ha^{-1}). In 2004, the average seed yield of chickpea was 10% higher when grown on barley stubble, and 21% higher when grown on wheat stubble, compared to conventional summerfallow (Fig. 6).

Chickpea grown on summerfallow at Shunavon did not reach full maturity due to excessive moisture in the fall, whereas chickpea grown on summerfallow at Swift Current in 2004 contained 45% green seeds due to incomplete maturity prior to the onset of a killing frost (data not shown). In the normal year of 2005, crops grown on the three stubble systems performed similarly, with no significant differences in seed yield. In the dry/warm year of 2006, chickpea yields averaged 67% higher when grown on summerfallow compared to barley stubble, and nearly double the yield of chickpea grown on wheat stubble.

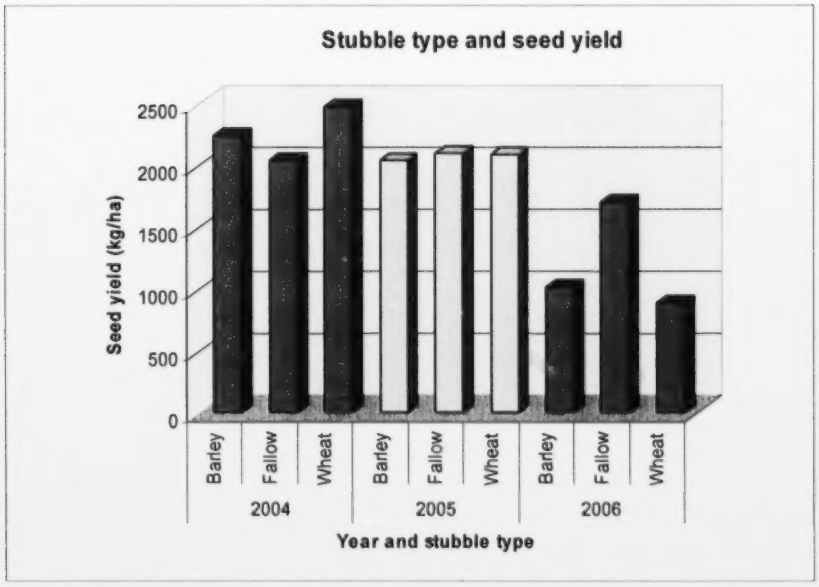

Fig. 6. Seed yield of chickpea grown on barley and wheat stubble and on conventional summerfallow in 2004, 2005, and 2006, in southwest Saskatchewan.

b) ***Yield differences among sites and varieties***

On average, CDC Frontier produced the highest seed yield and CDC Xena the lowest under the same growing conditions (Fig. 7). The ranking of varieties in terms of seed yield were consistent across the three years; CDC Frontier >CDC Anna >Amit >CDC Xena, in a decreasing order.

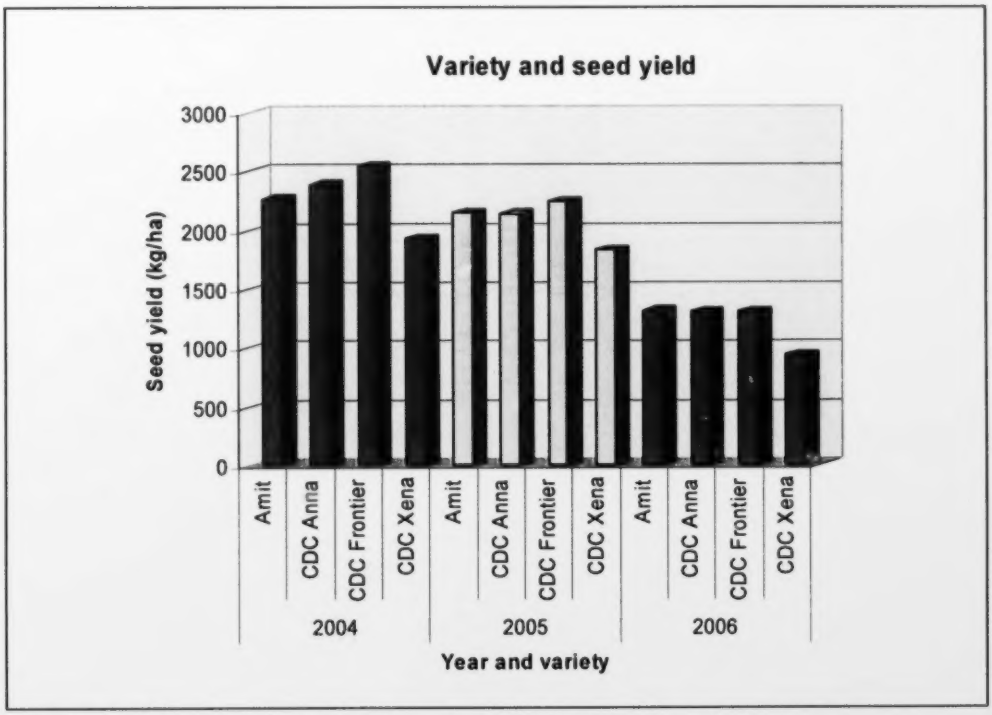

Fig. 7. Seed yield of four chickpea varieties tested in 2004, 2005, and 2006, in southwest Saskatchewan. Data were averages over stubble types and fertility treatments.

When the seed yield of CDC Frontier and CDC Xena was plotted against the wide range of environments experienced during the study years (i.e., two sites in each of three years on each of the three seedbed conditions), CDC Frontier showed consistently higher seed yield than CDC Xena (Fig. 8). Also, CDC Frontier displayed greater yield stability over the varying environmental conditions than CDC Xena. This was partly due to the responses to ascochyta blight; where CDC Frontier showed consistently more resistance to the disease than CDC Xena (data not shown).

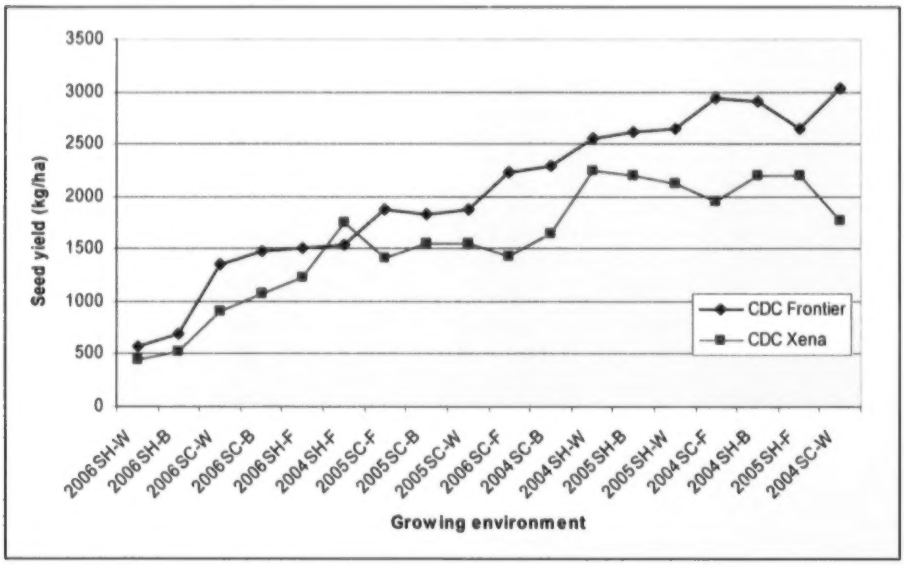

Fig. 8. CDC Frontier and CDC Xena seed yield response to 18 environmental conditions in southwest Saskatchewan (where, for example, 2006SH-W means chickpea grown on wheat (W) stubble at Shaunavon (SH) in 2006).

Overall, seed yields were similar between the two experimental sites in 2004. In 2005, however, seed yields were higher at Shaunavon than at Swift Current, but the yield was lower at Shaunavon than at Swift Current in 2006 (Fig. 8). Crops at the Shaunavon site experienced more intensive drought conditions, resulting in low seed yield in 2006 compared to Swift Current.

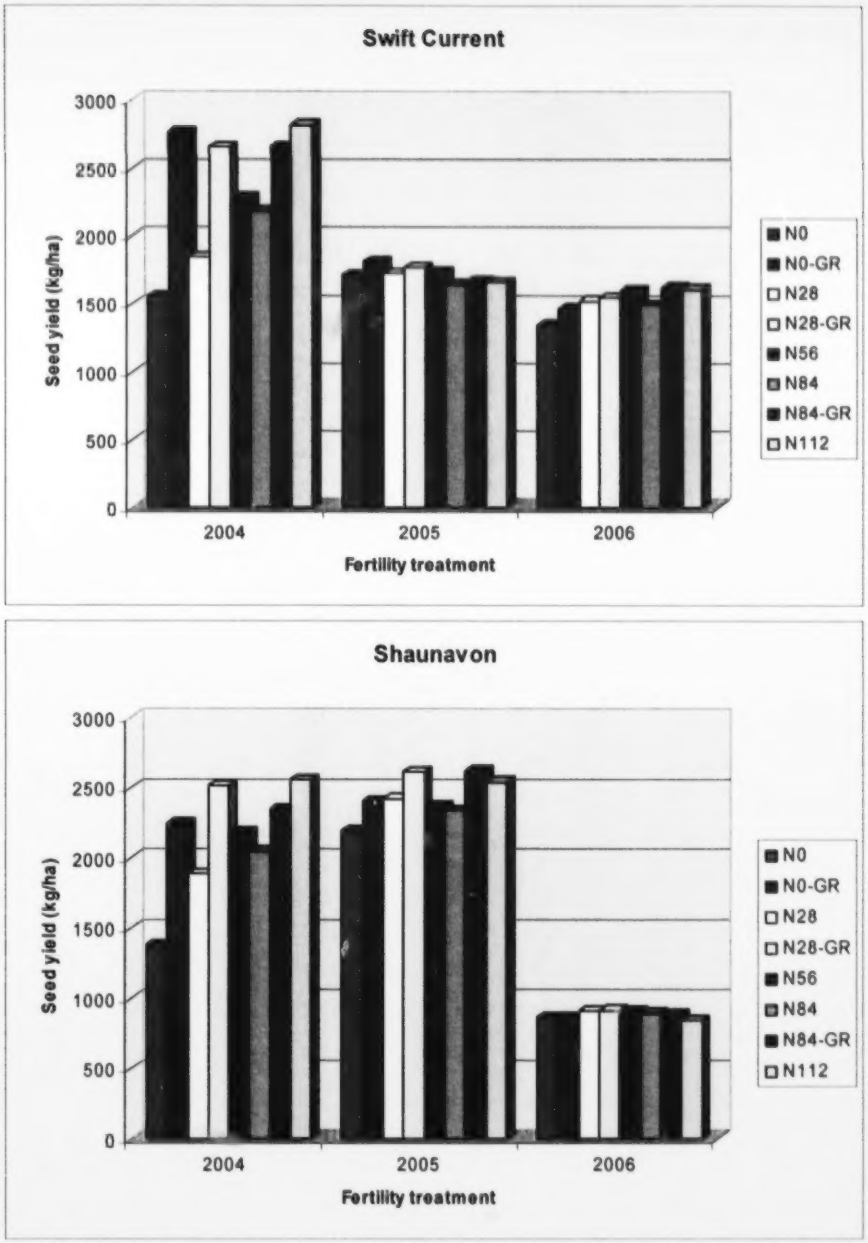

Fig. 9. Seed yield of chickpea grown under various inoculations/fertilization regimes at Swift Current (top) and Shaunavon (bottom) in 2004, 2005, and 2006.

c) ***Fertility treatments effect on seed yield***

Averaged over the six site-years, plots that were not supplied with either N fertilizer or inoculant (i.e., 0N check treatment) produced seed yields of 1500 kg ha^{-1} or less, whereas the seed yield of chickpea that was inoculated with *Rhizobium* was 27% higher than the check. The seed yield of chickpea supplied with N fertilizer at the rates of 28 and 56 kg N ha^{-1} but no *Rhizobium* averaged 18% greater than the No-N No-inoculation check (Fig. 9). Plots that received *Rhizobium* inoculant plus N fertilizer at the rates of 28 and 84 kg N ha^{-1} produced yields similar to or slightly higher than those that were inoculated with *Rhizobium* without fertilizer.

Seed yield response to soil fertility or inoculation was greatly influenced by weather conditions (Fig. 9), which in turn influenced the proportion of green seeds in harvested seed lots (Fig. 10). In the wet/cool year of 2004, plots that received N fertilizer at the rates of 28 and 56 kg N ha^{-1} produced a greater proportion of high quality, marketable seeds due to earlier maturity, whereas plots that were inoculated with *Rhizobium* produced a larger proportion of green seed due to delayed maturity. Percent of green seed was less than 2% in 2005 and near zero in 2006 regardless of fertility treatment.

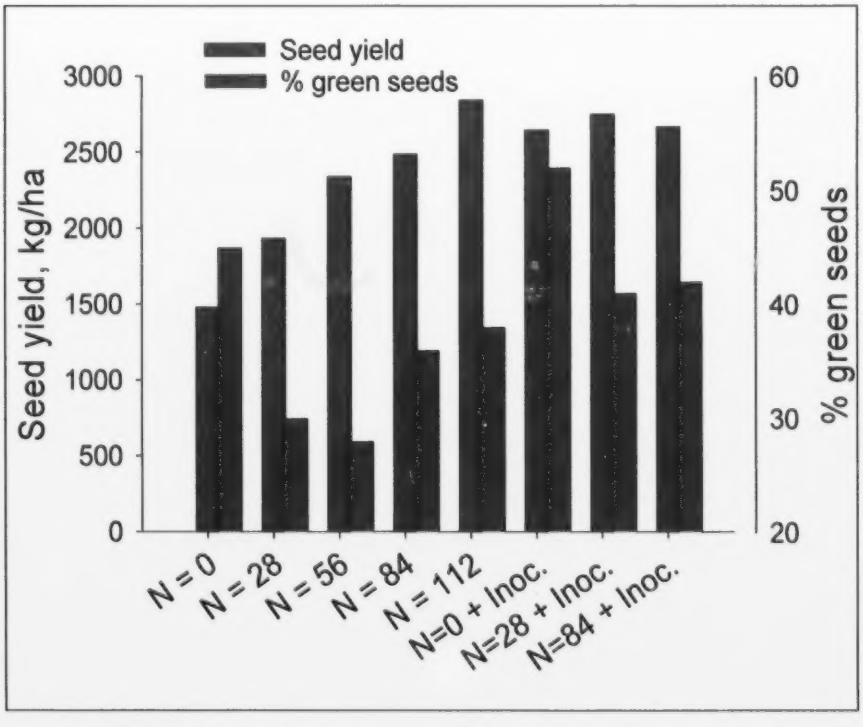

Fig. 10. Seed yield and percent of green seeds in harvested seed lot for chickpea grown in the wet year of 2004. Percent green seed was less than 2% in 2005 and 2006 and there was no difference among treatments.

SEED SIZE DISTRIBUTION IN KABULI CHICKPEA

a) ***Year, stubble, and variety effect on seed size distribution***

Among the three years, the highest percentage (69%) of ≥9 mm diameter seeds was obtained in 2004 in the CDC Xena seedlot, and lowest proportion of ≥ 9mm diameter seed (42%) was obtained in 2006 (Fig. 11). Drought conditions in 2006 shortened the period of seed-filling, resulting in smaller seed size.

Averaged across the six site-years, 24% of the seed for CDC Frontier was ≥9 mm diameter, 50% between 8 to 9 mm, and the rest in the 7 to 8 mm size category. In contrast, CDC Xena produced 59% of seed with ≥9 mm diameter, of which a 22% of these seeds had diameters greater than 10 mm in size.

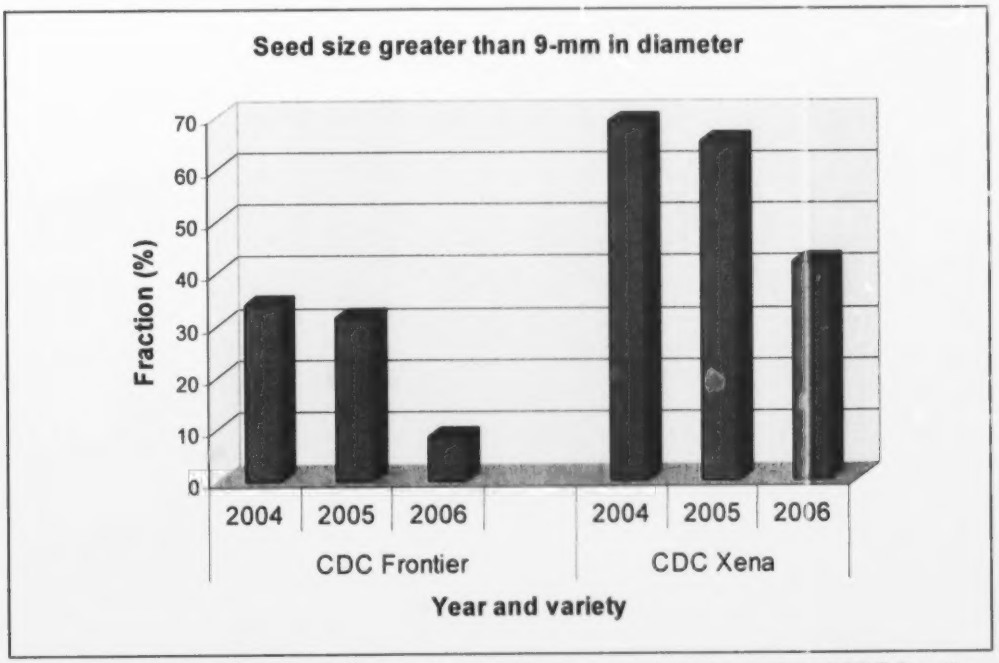

Fig. 11. The fraction of seed greater than 9-mm in the harvested seed samples of CDC Frontier and CDC Xena in 2004, 2005, and 2006.

Stubble systems also influenced seed size distribution for both CDC Frontier and CDC Xena (Fig. 12). CDC Xena grown on barley stubble produced 59% of seeds ≥9 mm, 6 percentage points higher than for CDC Xena grown on wheat stubble. The benefit of growing kabuli chickpea on conventional summerfallow was realized only in the dry year of 2006 when the fallow-grown CDC Xena produced 60% of ≥9 mm seeds, significantly higher than when grown on barley (35%) or wheat (31%) stubble.

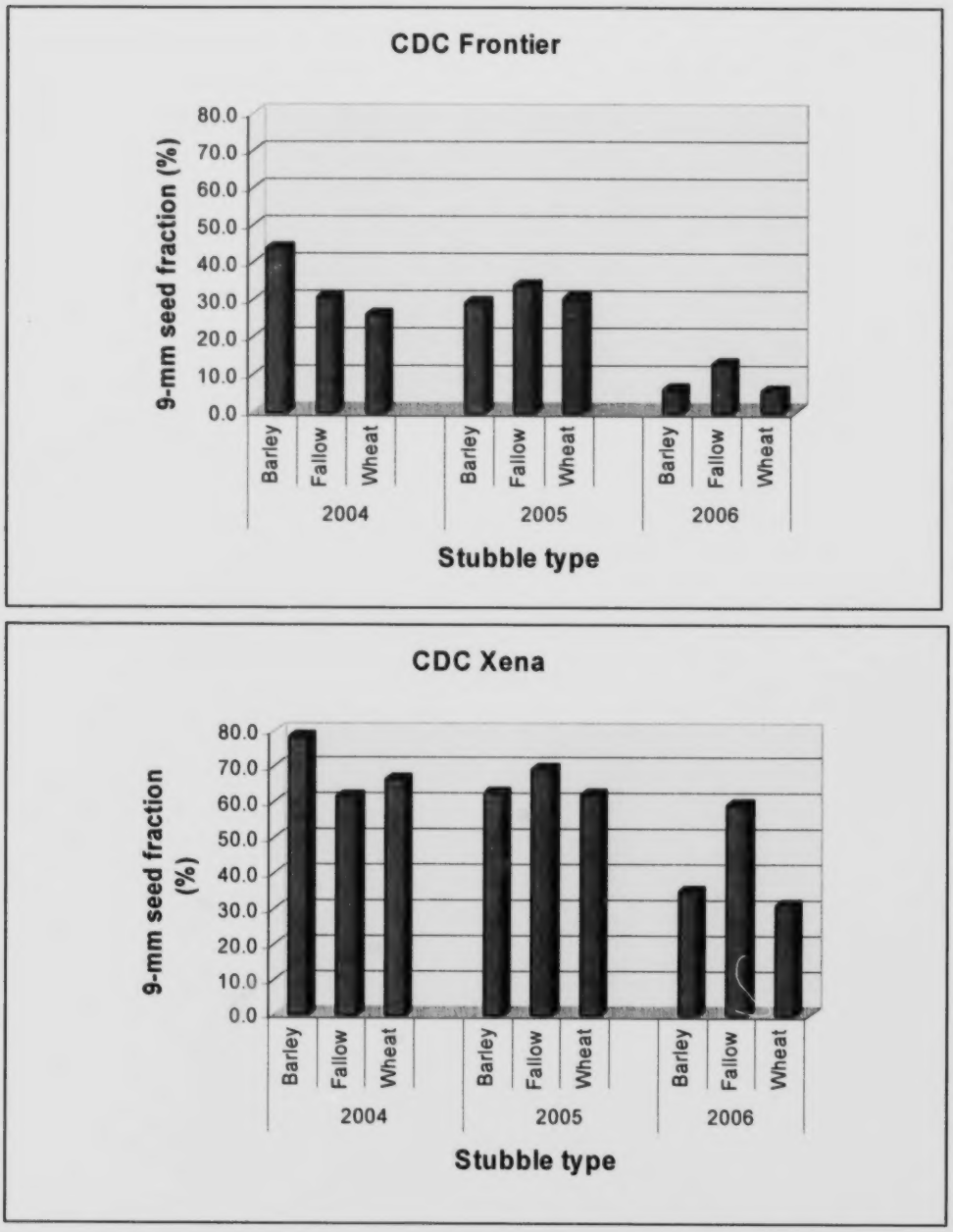

Fig. 12. Fraction of seeds greater than 9-mm in diameter for CDC Frontier (top) and CDC Xena (bottom) grown on barley and wheat stubble and on summerfallow in 2004, 2005, and 2006.

b) ***Fertility and inoculation effect on seed size distribution***

The use of *Rhizobium* granular inoculant consistently increased the proportion of ≥9 mm diameter seed for CDC Frontier compared to treatments that received N-fertilizer or no-N no-inoculant (28% versus 22%); however, the trends were not inconsistent for CDC Xena (Fig. 13).

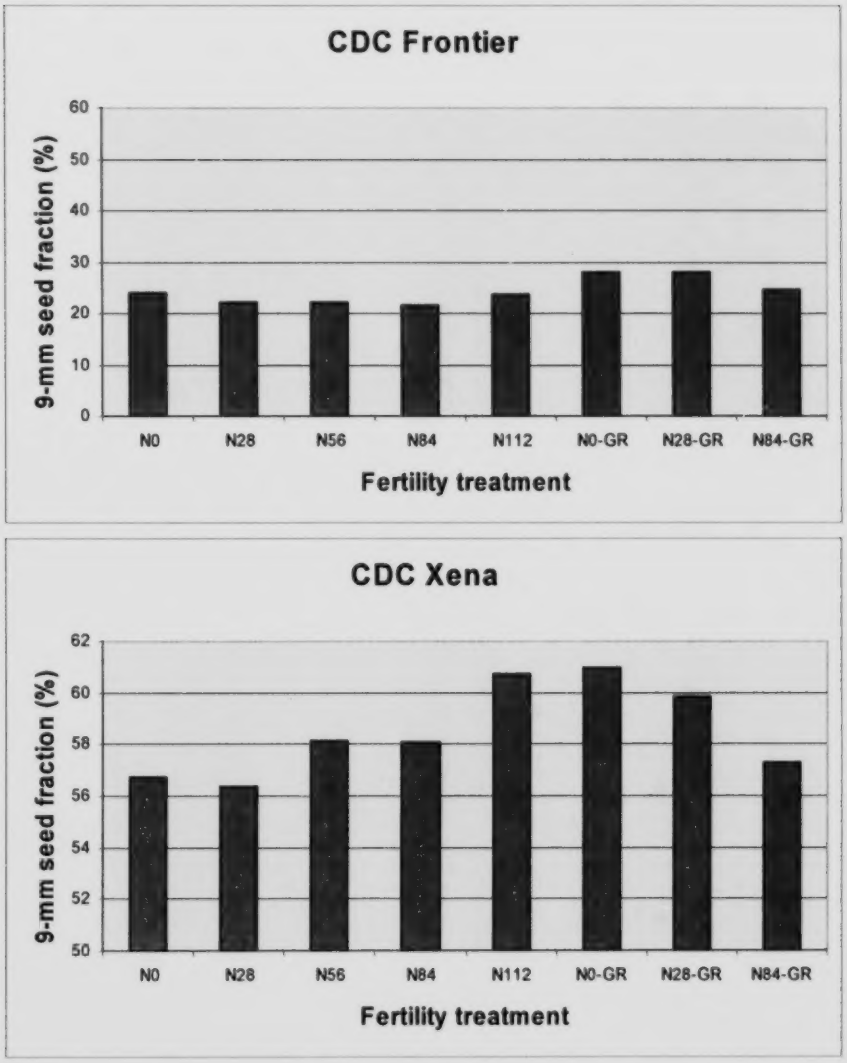

Fig. 13. The effect of fertility treatment (inoculant versus N fertilizer) on the fraction of seed greater than 9-mm in diameter for CDC Frontier (top) and CDC Xena (bottom) averaged across six site-years.

ROOT NODULATION

a) ***Year and stubble type effect on nodulation***

Nodulation was determined on chickpea roots at 1st flower and again at the end of flowering in each year (Table 5). Both the number of nodules and nodule dry weight were significantly lower on chickpea grown on summerfallow compared to stubble; this was consistent across the three years. Higher residual soil N on summerfallow decreased nodulation activity. Nodulation on the 2006 chickpea was a fraction of the nodulation observed in the 2005 chickpea crop, and lower than the nodulation observed on the 2004 chickpea crops. Drought conditions in 2006 minimized nodulation activity in chickpea.

Table 5. Nodule counts and nodule dry weight per plant measured at 1st flower and the end of flowering on chickpea grown on barley and wheat stubble and on summerfallow in southwest Saskatchewan, 2004-2006.

Year	Stubble type	1st flower		End of flowering	
		# of nodules	Nodule dry Wt (mg)	# of nodules	Nodule dry Wt (mg)
2004	Barley	6.6	128.3	7.8	89.3
	Fallow	6.2	91.1	7.8	80.3
	Wheat	8.3	135.8	9.4	129.5
Significance (P<0.05)		ns	**	**	**
2005	Barley	16.6	422.9	16.8	198.4
	Fallow	16.6	287.7	15.5	92.1
	Wheat	15.3	428.6	16.8	195.9
Significance (P<0.05)		*	**	**	**
2006	Barley	6.9	29.3	6.2	31.7
	Fallow	4.9	11.5	3.8	13.2
	Wheat	6.3	23.5	7.2	26.1
Significance (P<0.05)		*	**	**	**

*, **, and NS indicate significant at P<0.05, P<0.01, and Not significant, respectively.

As expected, application of N fertilizer in chickpea significantly decreased the number of nodules and nodule dry weight in chickpea (Fig. 14). The effect was more pronounced when nodulation was measured at 1st flowering compared to at the end of the flowering period. On chickpea, active nodulation usually begins at the start of flowering.

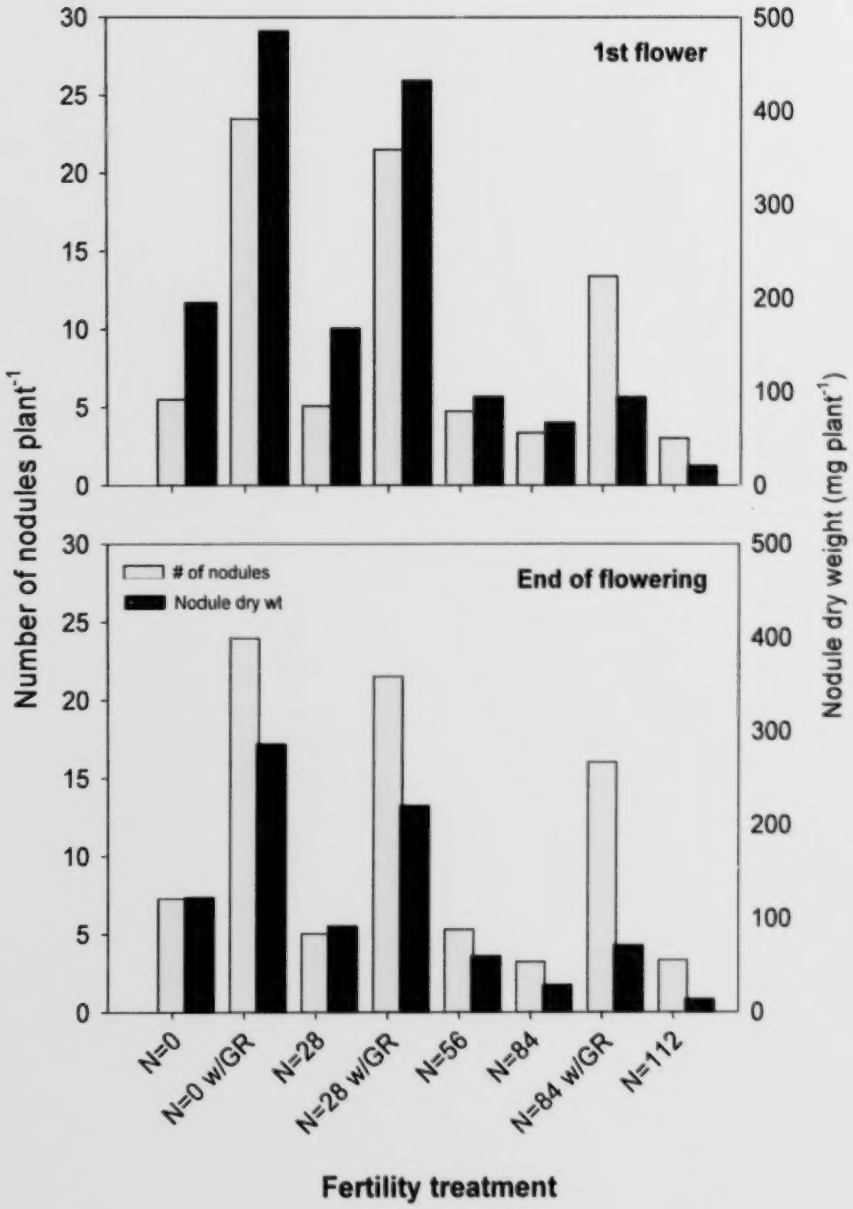

Fig. 14. Number of nodules and nodule dry weight measured at 1st flower (top) and at the end of flowering (bottom) on chickpea receiving different fertility/inoculantion treatments. Data were averages over all sites and stubble types.

b) ***Cultivar differences in nodulation***

Year had significant impact on nodulation for both desi and kabuli chickpea. In each of the three years and on average for the treatments that received *Rhizobium* inoculant, kabuli chickpea had consistently greater nodulation measured as number of nodules and nodule dry weight than desi chickpea (Table 6). The difference in nodulation between the two chickpea types was greater than 50% at 1st flower, with the difference declining to 46% at the end of flowering. Greater seed yield in CDC Frontier than CDC Anna was probably related to the greater nodulation activity during flowering for CDC Frontier.

Table 6. Nodulation per plant measured at 1st flower and the end of flowering on the roots of desi chickpea 'CDC Anna' in comparison to kabuli chickpea 'CDC Frontier' grown at southwest Saskatchewan 2004-2006.

Year	Chickpea type and cultivar	1st flower		End of flower	
		# of Nodules	Nodule dry Wt (mg)	# of Nodules	Nodule dry Wt (mg)
2004	Desi, CDC Anna	5.4	93	6.8	93
	Kabuli, CDC Frontier	9.5	172	10.5	126
2005	Desi, CDC Anna	12.1	344	13.7	160
	Kabuli, CDC Frontier	19.9	507	19.9	235
2006	Desi, CDC Anna	5.2	20	5.4	20
	Kabuli, CDC Frontier	8.1	33	8.1	37
3-yr Mean	Desi, CDC Anna	7.6	152	8.6	91
	Kabuli, CDC Frontier	12.5	237	12.8	133
	Kabuli over Desi (%)	65	56	48	45
	Significance ($P<0.05$)	**	**	**	**

*, **, and NS indicate significant at $P<0.05$, $P<0.01$, and Not significant, respectively.

Soil N Changes During The Growing Season

Soil N was measured during the 2005 growing season at seeding, during early flower, late flowering, and at harvest to a depth of 120 cm. The results showed that the fields which received higher rates of N fertilizer at seeding still had higher soil N at early- and late-flowering (Fig. 15). Soil N declined to near the spring soil N by harvest time in plots that received less than 84 kg ha^{-1} of N. The plots that were fertilized at rates over 84 kg ha^{-1} showed greater soil N at harvest than at spring seeding. These results indicate that a fertilizer rate of 84 kg N ha^{-1} is the maximum N that chickpea crop would require. Summerfallow fields had great amounts of N at spring, but decreased by flowering time.

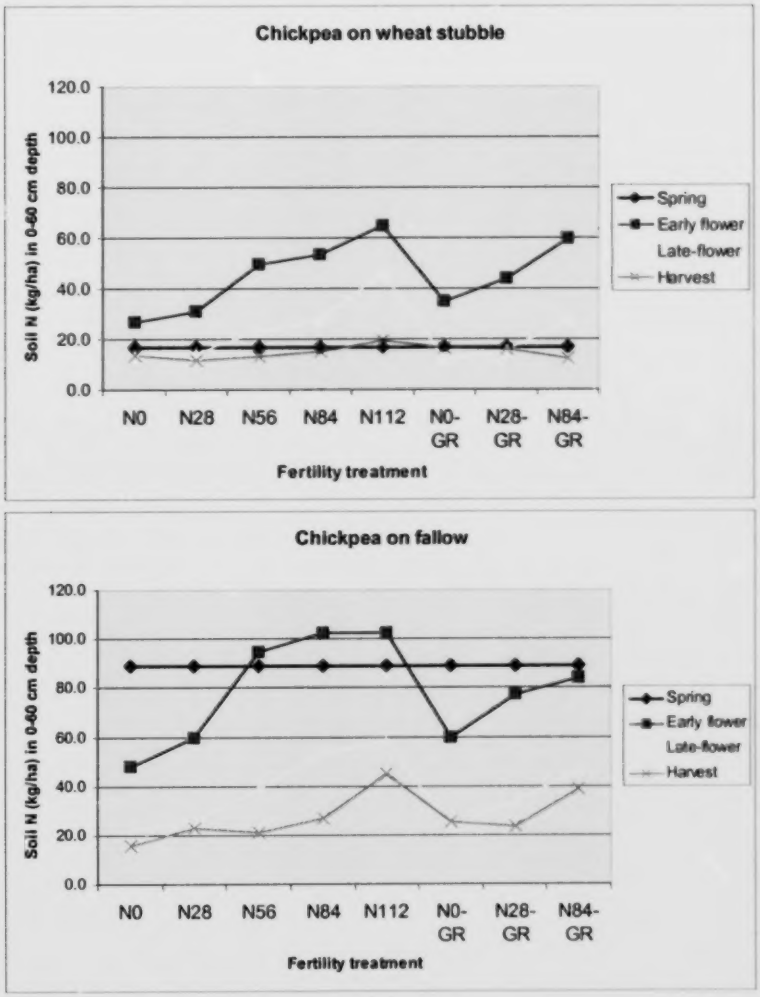

Fig. 15. Soil N changes during the 2005 growing season in the plots of chickpea that were fertilized with different rates of N in comparison with the plots that were inoculated with *Rhizobium*.

WATER RELATIONS

Growing season (May-August) precipitation encountered in this study ranged from 106 to 283 mm across the six site-years (Fig. 16). In general, seed yields of all varieties increased as precipitation increased (top graph) while the protein content of the grain decreased linearly (bottom graph). CDC Xena had consistently lower seed yield across the varying environments, while CDC Anna had consistently lower protein content. It is noteworthy that the protein content in chickpea seed ranged from 12% to 25%; such a range in protein content was larger than we normally expected.

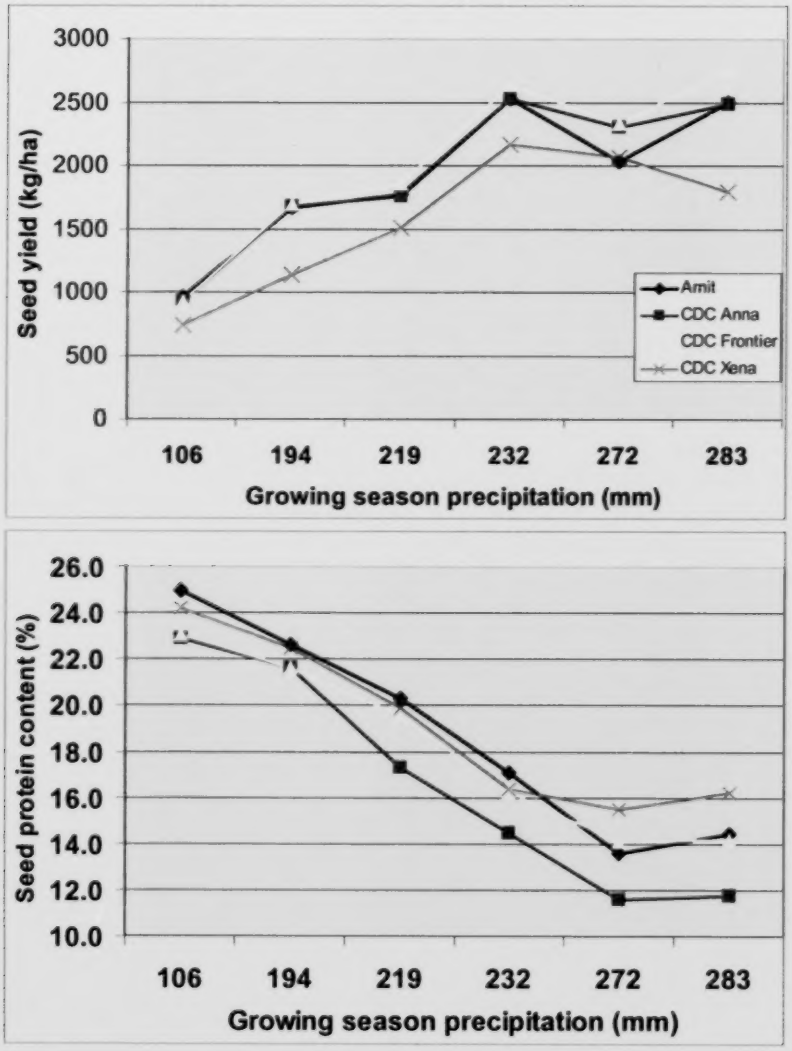

Fig. 16. Changes in seed yield and protein content of chickpea grown under various environmental conditions.

CONCLUSIONS

Chickpea expresses strong indeterminacy; under favourable growing conditions, the plants continue vegetative growth without setting pods, fill only a few pods, or unable to mature in a timely manner. The production of chickpea faces unique challenges in western Canada, including (i) rainfall in the late part of growing season induces vegetative growth and re-growth, (ii) declining temperatures in the fall delay chickpea maturity, (iii) the short-season in western Canada meets the minimum requirement for chickpea maturity, and (iv) plants is often subject to late-fall frost damage.

The development of cropping strategies and practices that promote a timely maturity is based on the following scientific principles: (i) vigorous early vegetative growth allows an earlier pod setting, (ii) early set-pods monopolize photosynthetic assimilates and preclude the production of new podding sites on the plant, and (iii) reproductive sink uses all available assimilates, helping cease of the production of new vegetative tissues.

The results from this multiple-site multiple-year research project showed that early N supply to chickpea plant promoted vigorous vegetative growth, giving rise to an earlier pod setting and thus early maturity. The maturity of chickpea varied significantly, dependent upon year, cultivar, seedbed condition, and soil fertility.

In normal to wet/cool years, chickpea that received no-N and no-inoculant, or inoculant only, matured latest. The use of fertilizer at the rates of 28 to 56 kg N ha^{-1} advanced maturity by 13 days on average. Early-matured chickpea produced high quality seed, whereas the late-maturity resulted in high proportions of green seeds. In dry years, only marginal differences were found among fertility/inoculation treatments. Drought conditions in dry/warm years accelerated crop maturity regardless of soil fertility. In dry/warm seasons, chickpea maturity may not be an issue in the commercial production of western Canada.

This study showed that fertilizer N can be used as a TOOL to reduce risks associated with indeterminate growth habit in chickpea. This study also suggests that new types of *Rhizobium* inoculants are needed for chickpea. Ideal *Rhizobium* inoculants would be the ones that start fixing nitrogen sooner after plants emerge; this will give rise to an early boost of vegetative growth, and that any N-fixing activity should cease totally near the end of flowering; this will help determinate the indeterminate growth of chickpea.

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